

Citation for published version:

Spiga, I, Caldwell, GS & Bruintjes, R 2016, 'Influence of pile driving on the clearance rate of the blue mussel, *Mytilus edulis* (L.)', *Proceedings of Meetings on Acoustics*, vol. 27, no. 1, 040004.
<https://doi.org/10.1121/2.0000277>

DOI:

[10.1121/2.0000277](https://doi.org/10.1121/2.0000277)

Publication date:

2016

Document Version

Publisher's PDF, also known as Version of record

[Link to publication](#)

The following article appeared in Spiga, I., Caldwell, G.S., & Bruintjes, R., 2016. Influence of Pile Driving on the Clearance Rate of the Blue Mussel, *Mytilus edulis* (L.), 27, 040005 and may be found at <http://dx.doi.org/10.1121/2.0000277>. Copyright 2016 Acoustical Society of America. This article may be downloaded for personal use only. Any other use requires prior permission of the author and the Acoustical Society of America.

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Influence of Pile Driving on the Clearance Rate of the Blue Mussel, *Mytilus edulis* (L.)

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Citation: [Proceedings of Meetings on Acoustics](#) **27**, 040005 (2016); doi: 10.1121/2.0000277

View online: <http://dx.doi.org/10.1121/2.0000277>

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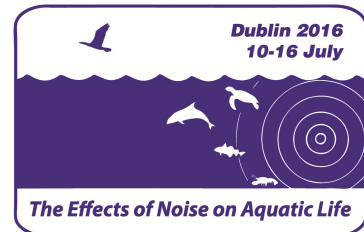
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Influence of Pile Driving on the Clearance Rate of the Blue Mussel, *Mytilus edulis* (L.)

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Underwater pile driving is typically undertaken during construction of offshore oil and gas platforms and wind farms and harbours. These structures generally need solid foundations – provided by large steel piles – that are driven into the seabed. Impact pile driving generates water-borne pressure and particle motions, which propagate through the water column and the seabed. Few studies have investigated the potential effects of underwater noise stimuli on bivalves. In current study, the influence of impact pile driving on clearance rate of the blue mussel (*Mytilus edulis*) was investigated in a semi-open field experiment. An experimental pile driving setup was constructed using a pile-driver and a steel pile. Under controlled conditions, individual mussels were exposed to experimental pile driving and ambient conditions, with the possibility to feed upon microalgae (*Tetraselmis suecica*). Mussels had significantly higher clearance rates during exposure to pile driving compared with individuals tested in ambient conditions. We suggest that mussels under pile driving conditions moved from a physiologically maintenance state to active metabolism to compensate for the stress caused by pile driving.



1. INTRODUCTION

Pile driving is typically undertaken during the construction of offshore structures, such as oil and gas platforms, and wind farms. The foundations of such structures are typically built by driving thick piles into the ground. Underwater impact pile driving generates acoustic energy that propagates as waterborne pressure and particle motion (Nedwell et al., 2003; Miller et al., 2014), and a proportion of the energy propagates through the substrate (Popper and Hastings, 2009; Hazelwood and Macey, 2016).

To assess the impact of anthropogenic (human-made) sounds and vibration in the aquatic environment, there is a need to fully describe the responses of animals in the field (Hawkins et al., 2015). Laboratory studies generally employ setups that allow detailed monitoring of the responses of animals to exposure of acoustic stressors. However, the acoustic conditions inside laboratory tanks generally differ from those in the acoustic free-field (Rogers et al., 2016). When studying bottom-living invertebrates that are believed to be sensitive to particle motion and ground vibrations, the differences between exposure to acoustic stressors in tank and free-field conditions could be especially important.

There are only few studies that investigate the effects of acoustic exposure on aquatic invertebrates. A comprehensive understanding of such effects is precluded by a lack of knowledge of the sound detection mechanisms and thresholds of many aquatic invertebrates (Hawkins et al., 2015). There is, however, mounting evidence that supports the detection of particle motion and ground vibration of aquatic invertebrates (Mosher, 1972; Popper et al., 2001; Breithaupt, 2002; Roberts et al., 2015; Roberts et al., 2016). In mollusks, studies on the effects of acoustic stimuli have largely focused on cephalopods (Mooney et al., 2010; André et al., 2011; Fewtrell and McCauley, 2012), while few studies focused on the responses to underwater sound stimuli on the behavior of bivalves, such as valve closure and digging movements (Ellers, 1995; Kastelein, 2008; Roberts et al., 2015).

From a physiological viewpoint, anthropogenic sound may impact metabolism, growth, feeding rate and ultimately survival of marine invertebrates (e.g. in shellfish; Lagardère, 1982; Regnault and Lagardère, 1983). The shore crab (*Carcinus maenas*) has been shown to increase oxygen consumption when exposed to playback of boat noise (Wale et al., 2013b). For bivalves, measures of physiological change in response to anthropogenic sounds are rare, although a recent study showed that the Mediterranean mussel (*Mytilus galloprovincialis*) elevated biochemical stress biomarkers when exposed to low frequency acoustic stimuli (Vazzana et al., 2016).

The blue mussel (*Mytilus edulis*) is of great ecological and commercial importance as an ecosystem engineer (Lintas and Seed, 1994; Borthagaray and Carranza, 2007) as well as a key species used in aquaculture. The sensitivity of the blue mussel to anthropogenic sound has yet to be thoroughly documented; however, there is evidence of sensitivity to sinusoidal vibratory signals in the frequency range of 5 to 410 Hz (Roberts et al., 2015).

Clearance rate (the rate that filter-feeders remove suspended particles from water) is a reliable indicator of feeding activity in mussels (Riisgård, 2001). Increased clearance rates are linked to increases in metabolic demand (Pessatti et al., 2002; Resgalla Jr et al., 2007), for example as an adaptation to stressful conditions (Thompson and Bayne, 1972). Studies focusing on the effects of acoustic exposure on bivalves indicated that the acoustic stimuli increased shells closure (Mosher, 1972; Kastelein, 2008; Roberts et al., 2015). Closure of the shell is thought to be a defense mechanism against competitors or predators (Popper et al., 2001). Kastelein (2008) suggested that closure of the shell in response to vibration would reduce feeding.

This study aimed to investigate the effects of impact pile driving on the clearance rate of blue mussels. We used controlled experiments to explore whether mussels changed the rate of filtering on live microalgae (*Tetraselmis suecica*) when exposed to pile driving compared to ambient conditions. We hypothesized that the clearance rate of mussels would decrease as a consequence of shell closure elicited by pile driving (Kastelein, 2008). Alternatively, mussels might increase clearance rate in response to pile driving, as an adaptation to this stressful condition (Thompson and Bayne, 1972).

2. METHODS

A. ACOUSTICS WITHIN THE DOCK

The experiment was conducted at the Offshore Renewable Energy Catapult flooded dock in Blyth, UK. The physiological responses of individual mussels were monitored when exposed to ambient and pile driving conditions in a semi-open field experiment.

A steel pipe (length: 7.5 m, diameter: 16.5 cm, thickness: 0.65 cm) with a steel plate welded 50 cm from the bottom (size: 151 x 164 x 1.4 cm) was used as a simulation pile (Fig. 1). A post-driver (Wrag penna) mounted behind a tractor was used to provide pile driving strikes. The post-driver's hammer (200 kg), was raised approximately 0.70 m and struck the pile every 10 ± 1 s. The dock measured 93 m in length, 18 m in width, and it was 3 m deep (Bruitjes *et al.* in review). The dock had a simulated seabed (~ 3.5 m thick) that consisted of North Sea sand and small stones.



Figure 1. The pile driving set-up used: 1) the steel pipe; 2) post-driver hammer.

Measurements of sound pressure, particle motion, and ground vibration were made inside the dock throughout the entire period of the experiments (Table 1). Sound pressure was recorded at approximately 15 meters from the pile using a calibrated hydrophone (C55 Cetacean Research Technology; Sensitivity + Preamplifier Gain – Effective Sensitivity: -165dB, re 1V/ μ Pa) connected to a Fostex FR-2LE compact audio recorder (Recording/Reproduction Frequency 20 Hz - 20 kHz \pm 2dB; FS 44.1/48 KHz). Particle motion was recorded using an accelerometer (M30 accelerometer; sensitivity 0–3 KHz, manufactured and calibrated by GeoSpectrum Technologies, Dartmouth, Canada). Vibration was recorded using a geophone system utilizing three 10 Hz geophones (flat responses to velocity of 20 V/(m/s) from 16Hz to 160 Hz; principal wavelet frequencies of 20-30 Hz) and

an accelerometer level sensor (Hazelwood, 2012). The weather was sunny and the wind speeds below 10 m/s.

Table 1. Pile driving analysis of a sample at the flooded dock during the experiments.

| Recording system | 0-to-peak (dB ref 1 μ Pa) | 90% energy envelope | Rise time | SELss (dB re) |
|---------------------------|----------------------------------|--|----------------|-------------------------------------|
| Hydrophone | 182.11 | 19,836.48 (ms) | 10,251.11 (ms) | 158.47 (1 μ Pa ² ·s) |
| Accelerometer (x-axis) | | 8,071.08 (nm/s) | 8.97 (nm/s) | 45.58(1 nm/s) ² ·s |
| Geophone (Z wavelet) | 10 mV (pk/pk) | Peak vertical velocity 0.25 (mm/s) | | |

B. BLUE MUSSEL CLEARANCE RATE TEST

Mussels were collected in Blyth (51°25'51.24"N; 0°19'33.24"W) during low tide and held overnight in polystyrene tanks until the morning of the experiment. At the onset of the experiment each mussel was cleaned of any fouling organisms and placed in a clear plastic airtight container (1L) that was completely filled with a solution (1:4) of live microalgae (*Tetraselmis suecica*) and artificial seawater. Before the experiment commenced, a sample of 15 ml was taken and one drop of Lugol solution (5% iodine concentration) was added to fix the sample. The mussels were then lowered to sit upon the simulated seabed of the dock and were allowed to feed on *T. suecica* for 50 minutes during ambient or pile driving conditions; the containers were placed at 15 m from the pile driver. Samples were taken again at the end of the trials and subjected to the same fixing procedure. A total of 96 mussels were used, with 48 individuals exposed to ambient conditions and 48 to pile driving. Following experiments, several containers contained air bubbles, rendering these replicates unusable, which reduced the sample size to 37 mussels for ambient conditions and 45 for pile driving.

An indirect clearance rate method was used to measure the volume of water cleared of microalgae per unit time (in mL/h). Algae concentrations were determined using a Multisizer™ coulter counter®. The clearance rate (CR) was calculated from the decrease in algal concentration as a function of time using the formula:

$$\frac{V(\ln C_i - \ln C_f)}{t}$$

where V was the fluid volume, C_i is the initial algae concentration and C_f was the final algae concentration after time t (hour) (Coughlan, 1969; Nilin et al., 2012).

C. STATISTICAL ANALYSIS

An independent samples t-test (IBM SPSS statistics v.22) was used to determine whether there was a significant difference between clearance rates of mussels exposed to ambient versus the pile driving conditions. All reported p-values are two-tailed and results were considered significant at an alpha value of 0.05.

3. RESULTS

Clearance rate in mussels exposed to pile driving was significantly higher than those exposed to ambient noise (noise treatment: $t_{1,78} = 2.541$, $p = 0.013$; Fig. 2).

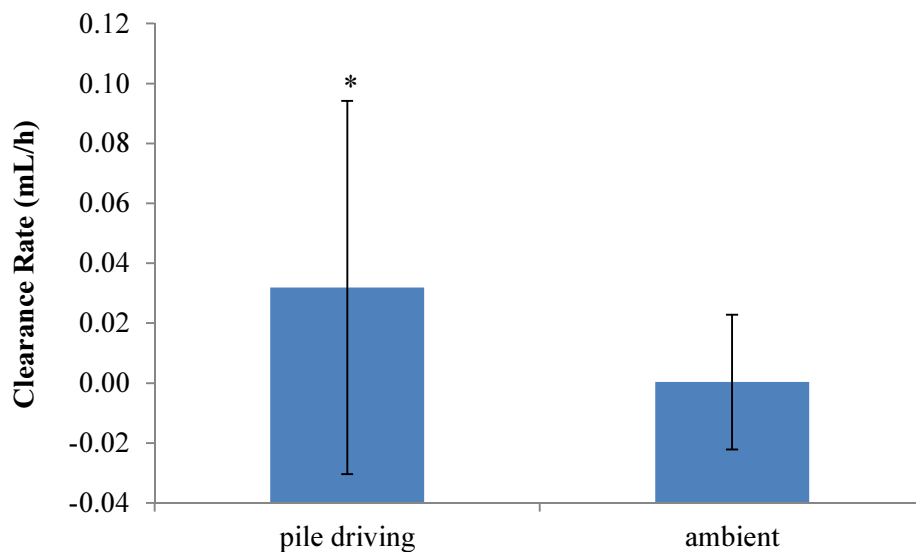


Figure 2. Mussel clearance rate (mean \pm SD) after exposure to pile driving and ambient conditions. * indicates significant results. $N_{\text{ambient}}=37$; $N_{\text{piling}}=45$.

4. DISCUSSION

This study showed that blue mussels had higher clearance rates during pile driving activity than during ambient conditions, indicating that pile driving influenced mussel feeding. Mussels' size did not have any significant effect on these measurements (data not shown). Several other aquatic invertebrates have shown behavioral and physiological responses to sound (e.g. Chan et al., 2010; Mooney et al., 2010; Wale et al., 2013a; b; Roberts et al., 2015; Roberts et al., 2016). However, former studies have predominantly been conducted using sound playbacks. The methodological advantage used in this study is that it was carried out in a semi-open field using a small-scale experimental pile driver. This setup allowed the acoustic energy to propagate over a large area and included both sound pressure and particle motion propagation in the water column as well as in the sea bed.

Few studies have shown that bivalves are sensitive to particle motion and vibration. Ellers (1995) suggested that behavioral response (jumping out of the substrate) of clams (*Donax variabilis*) was enhanced by changes in particle motion induced by low frequency wave sounds. During impact pile driving, ground vibrations are believed to be the primary source of disturbance (Hazelwood, 2012; Hazelwood and Macey, 2015; 2016). Our study strongly suggests that blue mussels sensed vibration during the real pile driving activity. This is supported by Roberts et al. (2015) who reported sensitivities for blue mussels to playbacks of impulsive vibration created by an electromagnetic shaker. In current study the peak velocity for one strike was 0.025 m/s measured at approximately 25 m range. These levels are higher than the sensitivity thresholds of blue mussels found in Roberts et al. (2015).

The higher clearance rate found here could be due to an increase in active metabolism as a consequence of stress during pile driving. The 'active metabolism-stress' hypothesis, which states that organisms increase metabolism when exposed to stressors, is supported by previous studies. For instance, Pessatti et al. (2002) found that brown mussels (*Perna perna*) maintained in a lead poisoned environment had higher filtration rates, likely induced by

compensatory changes in behavior and energetic distribution of the metabolic activity. Additionally, blue mussels are known to shift their routine state to a state of enhanced activity when submitted to acute shocks (Widdows, 1973). It is possible that during pile driving mussels shift their physiological state from a routine to an active state to compensate for the initial stress due to pile driving. However, if an increase in clearance rate is not matched by high food availability, active animals could risk encountering resource limitations, i.e. a mismatch between energy expenditure and energy capture. Over a sustained period, this mismatch may have detrimental fitness and survival implications.

The natural swimming behavior of the flagellated microalgae used here could have been affected by pile driving. Currently, there is a lack of knowledge of the effects of pile driving on the behavior of microalgae. However, there are commercial applications that use ultrasound to reduce microalgae blooms (reviewed in Lürting and Tolman, 2014), which suggest that algae might be sensitive to pressure variation. Because of the airtight 1 L experimental containers used, it is unlikely that the microalgae could have avoided being filtrated from the water by the mussels even when moving at full speed. We believe therefore that the difference in clearance rate found between treatments is predominantly caused by the mussels.

Present work indicates that blue mussels are sensitive to impact pile driving and respond physiologically by increasing their filtration rate. Further experiments, including behavioral observations, are required to determine the complementary effect of the stimulus on, for example, valve gaping and shell closure. Considering the high variability in the filtration performance of this species to biotic and abiotic factors (Riisgård, 2001), additional experiments that include assessment of the effectiveness of feeding and fecal content could help elucidate how costly the physiological response found in current work is and to what extent it would affect fitness.

Different environmental conditions, substrates, water depths, etc., all influence the propagation of acoustic energy (Thomsen et al., 2006; Götz et al., 2009; Hazelwood and Macey, 2016). The pile driving setup used here simulated a small-scale pile driver. It is likely that the energy produced by a larger pile driving setup is higher than that produced in our study, suggesting that the acoustic energy would propagate over longer distances, with the potential to impact invertebrates on a larger scale. For now, our results indicate that blue mussels are sensitive to pile driving and that pile driving can elicit increased clearance rates.

ACKNOWLEDGMENTS

We would like to thank: The Offshore Renewable Energy Catapult (formerly NaREC) facility and staff for hosting the experiment and supporting logistics. Newcastle University for providing the microalgae and associated equipment. Dr Stephen Simpson for providing the accelerometer. Dr Richard Hazelwood, R & V Hazelwood Associates LLP, for measuring and reporting on seabed vibrations. Jessica Lister, Fiona Birch, Harry Harding, and Tom Bunce for field assistance.

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